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Report No. 8926-005

Material - Nickel Base Alloy - Hastelloy R-235

Bauschinger Effects

Contract AF 33(657)-8926

A. Giuntoli, P. W. Bergstedt, H. C. Turner

1 December 1958



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Bauschinger Effects

Abstract

Ten per cent cold worked Hastelloy R-235 as received from the producer averaged 26.2 per cent lower in compression yield strength than in tensile yield strength. Stretching this material to 1 per cent elongation results in a most severe lowering of compression yield strength to 31.2 per cent below the as received tensile strength. Post stretching heat treatment at 1500°F for 2 hours restores equality of tensile and compressive yield strengths. The material displayed uniform elongation when stretched up to 9 per cent elongation.

Reference: Giuntoli, A., Bergstedt, P. W., Turner, H. C.,  
"Elimination of the Bauschinger Effect in 10% Cold Worked  
Hastelloy R-235," General Dynamics/Convair Report MP 58-290,  
San Diego, California, 1 December 1958. (Reference attached)



CONVAIR

A DIVISION OF GENERAL DYNAMICS CORPORATION

SAN DIEGO

STRUCTURES & MATERIALS LABORATORIES

REPORT MP 58-290

DATE 11-12-58

MODEL REA 7028

REVISED 12-1-58

TITLE

REPORT NO. MP 58-290

ELIMINATION OF THE BAUSCHINGER  
EFFECT IN 10% COLD WORKED  
HASTELLOY R-235

MODEL REA 7028

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CHECKED BY \_\_\_\_\_ NO. OF PAGES 7

NO. OF DIAGRAMS 4

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REVISIONS

NO.	DATE	BY	CHANGE	PAGES AFFECTED
1	12-1-58	A. G.	Additions to Conclusions.	1
2	12-1-58	A. G.	Additions to Procedure.	2
3	12-1-58	A. G.	Additions to Discussion	3

INTRODUCTION:

A shop method that is used to form parts from sheet material is classified as stretch forming. Stretch forming is a process of forming panels and cowls of large curvature by stretching sheet over a form of the desired shape.

This permanent plastic deformation gives rise to a phenomenon known as the Bauschinger effect. The Bauschinger effect is defined in the ASM Metals Handbook, 1948 Edition, as "The phenomenon by which plastic deformation of a metal raises the yield strength in the direction of plastic flow and decreases the yield strength in the opposite direction".

This report is intended to show a method of eliminating the Bauschinger effect in 10% Cold Worked Hastelloy R-235.

OBJECT:

- 1) To determine the severity of the Bauschinger effect in as received and plastically deformed 10% Cold Worked Hastelloy R-235.
- 2) To determine what thermal treatments are required to eliminate the Bauschinger effect in 10% Cold Worked Hastelloy R-235.

CONCLUSIONS:

- 1) Material as received from the producer averaged 26.2% lower in compression yield strength than in tensile yield strength. This is an indication of Bauschinger effect in the as-received material.
- 2) Additional tensile plastic deformation of 1% resulted in the most severe lowering of the compression yield strength (31.2% below the as received tensile yield strength).
- 3) The complete recovery of compression yield strength was realized with a heat treatment of 1500°F. for 2 hours.
- 4) The alloy displayed uniform elongation along a 12 inch gage length, up to 9% additional plastic deformation.

MATERIAL:

A sheet of 0.063 gage material, produced by the Haynes Stellite Company from their Heat Number RV-7269, was used for this test.

PROCEDURE:

Strips 1" x 18" were taken in the longitudinal direction for compression specimens; this size was chosen for convenience in those cases where stretching was required prior to compression tests. Strips 1" x 10" in the longitudinal direction were taken for the tensile specimens. The conditions tested are shown in Table I.

PROCEDURE: (Continued)

Where additional tensile deformation of 1%, 3%, and 9% was required, this was done in a Tinius Olsen 60,000 lb. Universal Testing Machine. The additional plastic deformation was recorded using a Tinius Olsen U-1 Extensometer recording the tensile deformation data on an autographic recorder.

The strips that were used for compression specimens were stretched over a 12 inch or longer gage length. After stretching, the elongation was measured in 1/4 inch increments over the entire gage length. Measurement was done with a steel scale graduated in 0.01 inch increments and a microscope at 40X magnification. It was estimated that the accuracy of measurement was  $\pm 1\%$ .

All heat treating was performed in a circulating-air laboratory furnace having a temperature spread in the working area of  $\pm 10^\circ\text{F}$ .

Tensile tests, using standard flat tensile specimens, were done in a Tinius Olsen 60,000 lb. Universal Testing Machine equipped with automatic x-y strain recorder. Compression testing was done in the same universal testing machine with a Boeing designed compression testing jig. Figure 1 shows the compression specimen used with the Boeing Jig.

RESULTS:

Table I - lists the tensile properties and the compressive yield strength of the conditions tested. Figure 2 shows the effect of exposure temperature on the tensile and compressive yield strength of the various conditions. Figure 3 shows the effect of exposure temperature on the tensile properties of as received material and material given an additional 9% tensile plastic deformation.

DISCUSSION:

Material, as received from the producer, averaged 26.2% lower in compression yield strength than in tensile yield strength. This indicates that the as received material already had incurred the Bauschinger effect. An additional 1% tensile deformation reduced the compression yield strength to 68.8% of the tension yield strength of the as-received material. Tensile plastic deformation of 3% and 9% tended to raise the compression yield strength but never higher than the as-received compression yield strength.

The amount of compression yield strength recovery with increasing exposure temperature was dependent on the amount of plastic tensile deformation the alloy had. Up to 1100°F. the compressive yield strength recovery is due in a large part to the elimination of the Bauschinger effect. The continuing increased in compressive yield strength in the temperature range of 1100°F. to 1500°F. appears to be caused by age hardening.

An increase of tensile yield and ultimate strength and a decrease in tensile elongation was noted when the as-received material was given an additional 9% tensile plastic deformation. This increase persisted through all the temperature ranges.

DISCUSSION: (Continued)

The room temperature tensile properties of the material were relatively unaffected, either in the as-received condition or with an additional 9% permanent deformation, up to 1100°F. In the temperature range of 1100°F. to 1500°F. a rapid increase of tensile ultimate and yield strength and a corresponding decrease in tensile elongation was observed. The observed increase of tensile yield and ultimate strength of the 9% tensile-plastically-deformed material over the properties of the received material in this temperature range, along with the compressive yield strength results, points to the importance of previous cold work on the aging response of this alloy.

At exposure temperatures in excess of 1500°F. a rapid over-age occurs as evidenced by the reversal of the trends for all the mechanical properties.

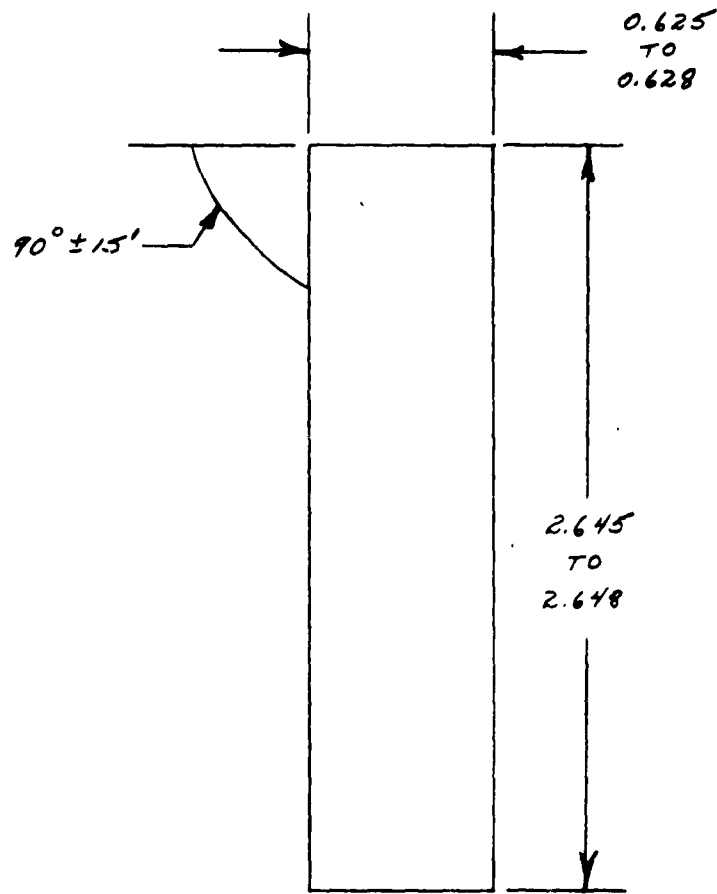
Over the entire 12 inch gage length, within the limits of measuring accuracy, the alloy displayed a uniform elongation measured at 1/4 inch increments. This was so regardless of the amount of additional permanent deformation.

In summary, it appears that a 85% or better recovery of compression yield strength, through the elimination of Bauschinger effect, is accomplished at 1100°F. A further increase in mechanical strength, probably due to aging, can be obtained by exposing the plastically deformed alloy to 1500°F. for 2 hours. Exposing the plastically deformed alloy to temperatures in excess of 1500°F. causes over aging and a rapid deterioration of room temperature mechanical strength. The alloy displays uniform elongation up to 9% additional plastic deformation.

Note: This report covers all the testing performed under MP 58-290 and MP 58-389.

The data from which this report was written are recorded in Materials & Processes Laboratory Notebook #965.





NOTES: ENDS MUST BE HELD WITHIN 0.0002 FLATNESS  
SIDES MUST BE HELD WITHIN 0.0005 PARALLELISM  
SURFACES MUST BE WITHIN 63 RMS

FIGURE 1 - TYPICAL COMPRESSION SPECIMEN USED IN CONJUNCTION  
WITH THE BOEING COMPRESSION JIG.

FORM 70  
CONSUME  
SAND 08100

TABLE I - TENSION AND COMPRESSION STRENGTH OF 10% COLD WORKED HASTELLOY R-235

TEMPERATURE (°F)	EXPOSURE TIME (HOURS)	TENSION PROPERTIES (AS RECEIVED)			TENSION PROPERTIES (AS RECEIVED - 10% COLD WORKED)			COMPRESSION YIELD STRENGTH (AS RECEIVED - 10% COLD WORKED)			COMPRESSION YIELD STRENGTH (AS RECEIVED - 10% COLD WORKED)		
		STRESS (PSI)	ELONGATION (%)	REDUCTION OF AREA (%)	STRESS (PSI)	ELONGATION (%)	REDUCTION OF AREA (%)	STRESS (PSI)	ELONGATION (%)	REDUCTION OF AREA (%)	STRESS (PSI)	ELONGATION (%)	REDUCTION OF AREA (%)
70	None	94.9	131.9	39.0	130.7	161.8	27.5	68.7	66.1	67.3	67.3	67.3	67.3
		93.7	134.5	34.5	125.5	146.3	29.5	67.2	63.5	67.6	67.6	67.6	67.6
		92.9	134.4	41.1	120.1	146.2	30.5	68.8					
		93.8	133.6	38.8	124.1	146.8	29.2	69.2	64.8	67.4	67.4	67.4	67.4
600	1/2												
800	1/2												
1000	1/2												
900	2	90.9	137.2	40.0	118.5	146.4	31.5	79.0	66.4	76.4	76.4	76.4	76.4
		92.7	136.8	40.5	120.0	147.6	35.5	80.2	65.9	76.4	76.4	76.4	76.4
		91.2	135.5	37.5	114.5	142.9	32.0	80.3	65.6	76.4	76.4	76.4	76.4
		90.6	134.5	39.2	112.7	146.3	34.0	79.9	65.9	76.4	76.4	76.4	76.4
1100	2	104.1	144.7	37.0	130.1	157.6	27.5	91.4	72.4	109.5	109.5	109.5	109.5
		100.1	141.1	38.5	126.7	155.5	28.5	82.3	72.6	108.7	108.7	108.7	108.7
		101.6	141.8	37.0	128.1	157.2	28.5	81.9	72.6	110.0	110.0	110.0	110.0
		101.9	142.5	37.5	126.3	156.8	28.2	81.5	72.5	108.4	108.4	108.4	108.4
1400	2	134.5	177.8	22.5	157.9	188.7	18.5	32.2	27.3	123.3	123.3	123.3	123.3
		135.6	175.7	22.5	155.5	186.2	16.5	32.0	27.2	123.3	123.3	123.3	123.3
		132.4	176.4	23.5	157.7	187.1	20.0	32.7	27.7	123.3	123.3	123.3	123.3
		134.2	176.6	22.5	157.0	187.3	18.2	26.5	26.5	123.3	123.3	123.3	123.3
1500	2	132.6	176.1	7.0	157.1	191.4	19.5						
		140.2	177.9	24.0	157.4	191.4	19.5						
		135.6	172.3	24.6	154.9	189.8	20.0						
		138.5	172.7	21.7	157.1	190.5	2.7						
1600	2	126.7	174.3	25.0	157.2	182.7	21.5						
		125.6	171.0	24.0	155.9	183.3	20.5						
		128.1	173.6	23.2	156.5	183.2	21.0						
		125.5	173.0	24.2	155.0	183.1	21.7						

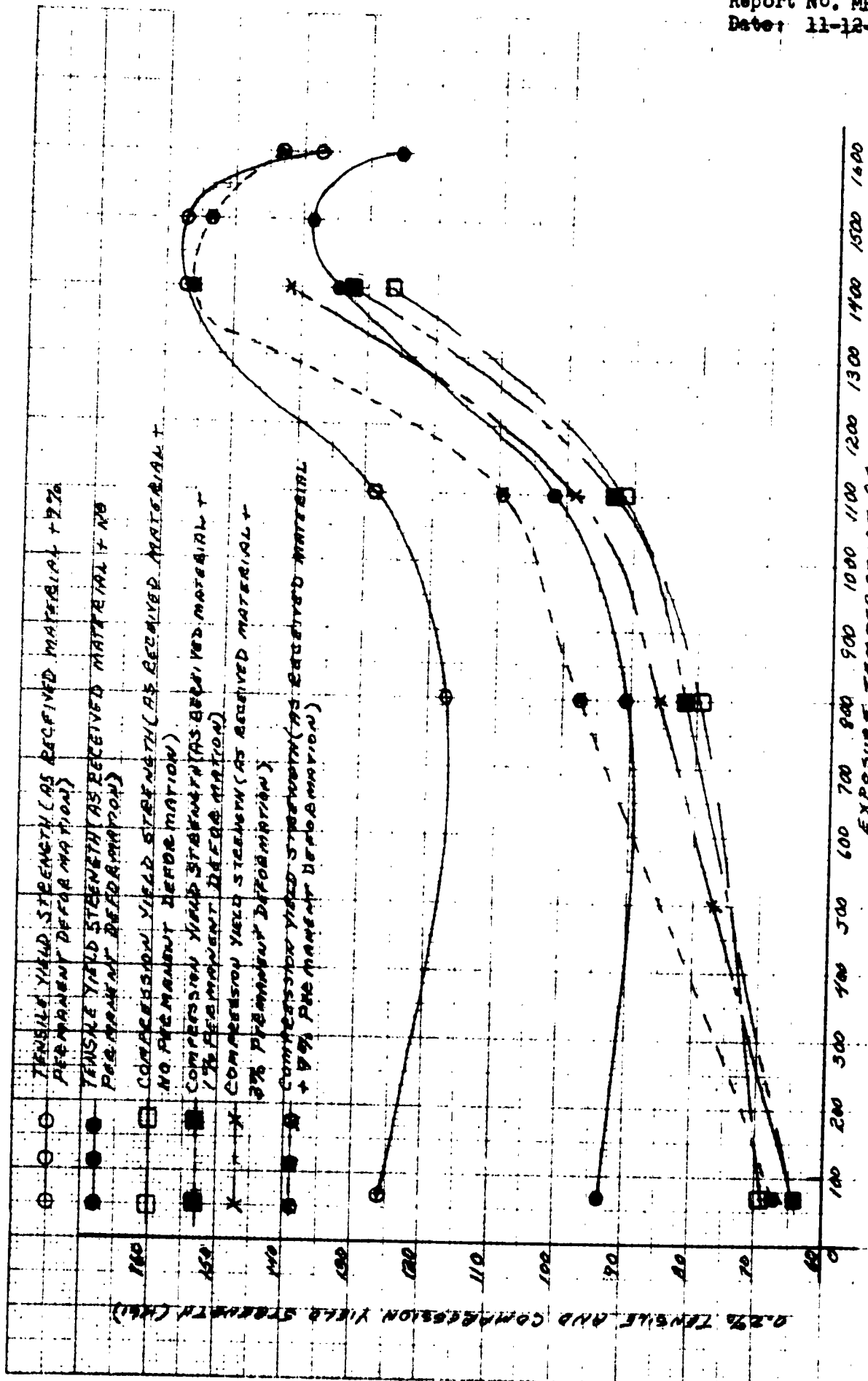


FIG. 2. ROOM TEMPERATURE TENSION AND COMPRESSION YIELD STRENGTH OF 10% COLD WORKED INCONEL B-205 AFTER VARIOUS TENSILE PERMANENT DEFORMATION AND EXPOSURE FOR 2 HOURS AT VARIOUS TEMPERATURES

3-N  
SILICIDE  
MOUNTED SHEET OF 1000  
ALUMINUM

TENSILE YIELD STRENGTH AND ULTIMATE STRENGTH (Mpi)  
ELONGATION (%)

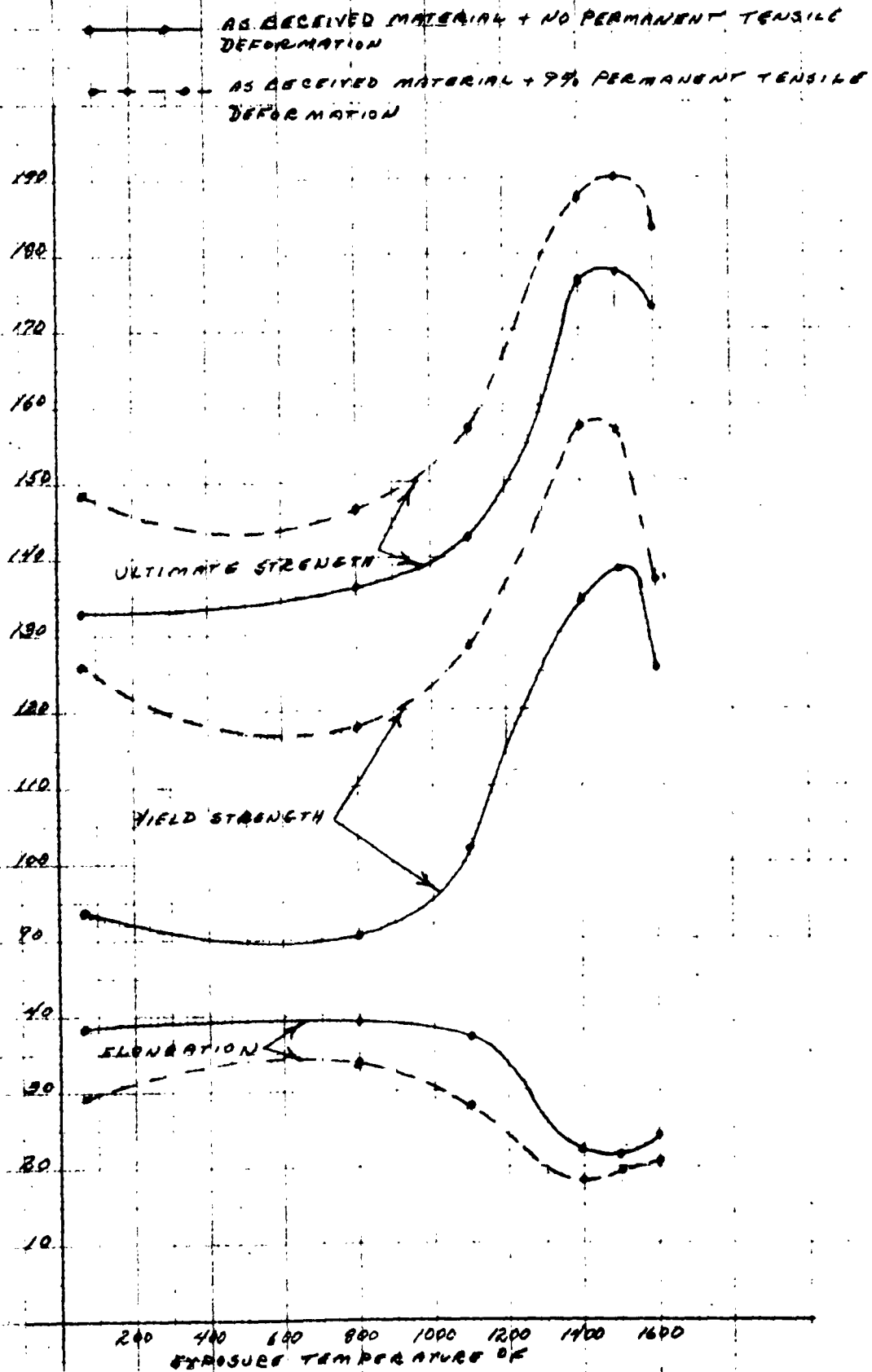


FIG. 2. APPROXIMATE TEMPERATURE TENSILE PROPERTIES OF 10% COLD WORKED HASTELLOY C-276 WITH NO TENSILE DEFORMATION AND 9% TENSILE DEFORMATION AFTER EXPOSURE FOR 2 HOURS AT VARIOUS TEMPERATURES